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The Harveian Lecture

ON

INDUSTRIAL FATIGUE.

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FOR a member of the same College in Cambridge and of the same hospital in London as William Harvey, it is a special honour to be invited to give this address in his memory. Industrial fatigue must have existed in Harvey's time, but under conditions so widely different from those now obtaining that it could not attract public attention and could not receive such scientific treatment as is possible to-day.

DEFINITION OF INDUSTRIAL FATIGUE.

I shall be expected at the outset to define precisely what is to be understood by industrial fatigue. It will be urged that since the ultimate aim of science is measurement, an exact knowledge of what it is that we are endeavouring to measure must be essential if our procedure is to be scientific. But do we not measure electricity despite our ignorance of its nature? And may we not by statistical methods even measure a common factor affecting a number of different phenomena, without knowing anything whatever of the nature of that factor beyond the fact that it is a common determinant, among others, of those phenomena?

TWO GROUPS OF TESTS.

Assuredly the earliest workers on the subject of industrial fatigue did not concern themselves with its definition or with any careful inquiry into its nature. They set about devising tests which would reveal its presence. Those tests fall into two groups. The first group consist of brief tests of efficiency which were applied to the worker at different times of the day or week, and compared in regard to their results. Thus the average of two or three successive grips of the dynamometer was registered, first, say, in the early

morning, then at mid-day, next in the early afternoon, and finally at the end of the day's work, and the difference or lack of difference between the strength of the worker's grip at different hours of the day was held to indicate the presence or absence of industrial fatigue. Other simple tests were employed in the same way—such as a few reaction times, keenness of sight or hearing, the delicacy of discrimination between two near simultaneous touches of the skin or the speed of learning, so as immediately and correctly to reproduce a short series of numbers or letters. And when it became obvious that the worker could simulate fatigue by intentionally doing worse at the tests in the course of their application, tests were introduced which were independent of voluntary control, such as involved a record of the pulse-rate or of the time the skin took to recover its colour after being blanched by momentary pressure.

But another important complicating influence still remained—that of the feelings. The worker might be at one time annoyed or at another relieved by being interrupted in his work in order that these tests might be applied to him ; in the early stages of their use he might be alarmed by the apparatus involved, or in later stages he might be bored by them. Such affective variations, together often with the effects of practice, could not fail to obscure the revelation of industrial fatigue, even if—as was tacitly assumed—the tests were competent to reveal its presence and to measure its degree commensurately with their results.

The second group of tests were in themselves tests of fatigability. A relatively lengthy task was imposed —e.g., repeated flexion and extension of a single finger-joint engaged in lifting a weight until the joint could no longer be moved, repeated additions of pairs of numbers, the erasure of a prescribed letter in printed matter, say for an hour, a work curve being obtained, movement by movement, or minute by minute, which was held to indicate the fatigability of the subject, the curves being compared at different times of the working day, week, or season. But here, again, the influence of practice often proved a serious practical difficulty. Moreover, the problem of whether, and if so how far, fatigue at a given occupation was local or general was overlooked. And the degree of correlation between industrial fatigue and the evidence of fatigue revealed by the tests was unknown and apparently unknowable.

Many of these tests, especially after experience sufficient to remove the complicating effects of practice, became so automatic and were carried out so unconsciously as to be incomparable with industrial conditions in which the work was more varied and

required the exercise of a certain skill and judgment. The tests were necessarily of a very simple character, measured by quantity rather than by quality of output. In view of all these difficulties, it is hardly surprising that the interpolation of so-called fatigue tests brought discredit on the early attempts to estimate industrial fatigue.

Nature of Fatigue.

Let us, then, turn to a consideration of the nature of industrial fatigue, dealing first with occupations especially involving muscular work. Here, it might be thought, is a field in which the ergograph, recording flexion and extension of an isolated joint within the intact organism, might yield serviceable evidence of the extent of fatigue. Here, too, it might be expected—from the resemblance of ergographic conditions to those of the muscle-nerve preparation —that our knowledge of the physiology of muscle would render valuable help in its application to industrial fatigue. We have reason to believe that the isolated muscle tires because it no longer has sufficient manufactured material (of the nature of glycogen) at its command which will enable further contraction to take place, breaking down into lactic acid, carbonic acid, &c., or because the muscle-fibres have become clogged by the non-removal and the accumulation of such poisonous products of decomposition.

But the ergographic tracing is not a simple record of either of these conditions. For, when the subject has reached the stage when he is quite impotent to produce further movement of his finger, he will immediately be able to furnish another good ergogram, if the weight which his finger is lifting be slightly reduced. From another aspect, too, the stage of absolute exhaustion which he has reached is only apparent, so far as his muscle is concerned. It will still readily contract if the stimulus of an electric current be applied to his arm over the appropriate peripheral motor nerve. The so-called fatigue effects revealed by the ergograph are very largely of nervous origin, due to afferent impulses ascending from the tiring muscle and inhibiting the transmission of efferent impulses which would otherwise throw it into action. They are protective against truly muscular exhaustion, and we are ignorant of the relation between such nervous inhibition and the degree of truly muscular fatigue occurring. We do know that under conditions of severe general fatigue such inhibition may fail, and thus a better ergographic tracing—i.e., a larger amount of work—may be compatible with increased fatigue. Such an experience occurred to my knowledge during a prolonged series

of ergographic records daily taken by the late Dr. Rivers, who one day felt so tired from an exceptionally arduous day's mental work that he was sorely tempted not to tire himself further with the taking of the usual evening's ergograph tracing. But, resisting the temptation, he obtained one of the best records of muscular work throughout the whole series of his experiments.

We have also to remember that the conditions under which the industrial worker carries out his daily work are very different from those under which an ergographic record is taken. The worker does not confine himself to the use of a single muscle. By varying his posture, as he tires, he often brings other muscles into play to carry out the same operations as heretofore. He does not work his hardest at each muscular contraction, as the ergograph demands of its subject. More or less unconsciously he adapts his expenditure of work to the length of his unbroken working spell or working day.

The fatigue which such a worker suffers is not merely or principally a fatigue of effort; it is also largely a fatigue of skill. There is no industrial work that is, strictly speaking, unskilled. For there is no occupation in industry in which there are not good and bad methods of carrying it out. The best worker is he who has become expert in the use of the best movements. He acquires his skill by coördinating visual, tactual, or auditory sensations with movements, by synthesising relatively simpler, previously acquired movements with one another so as to perform more complex movements, and by analysing and suppressing needless movements so as to obtain cleanness and economy of movement just as a clever artist eliminates all but the essentials in a sketch or caricature. Coördination, integration, and inhibition are thus the essential nervous processes for securing the minimal expenditure of muscular effort and for yielding the maximal efficiency of output. At the same time, the field of consciousness becomes reduced both in extent and in intensity. The need for widely diffused attention and for continuous judgment becomes replaced by the establishment and maintenance of an appropriate conscious attitude or posture in which the work is carried out to a large extent automatically. When fatigue arises, the discarded conscious attention to details is revived. Voluntary effort replaces intuitive behaviour, but with much less success. Output is reduced not only in quantity, but also in quality. The expert worker falls to the level of the inexpert worker. Old faults reappear. Finally, disorder replaces order of movement.

Moreover, apart from the fatigue of muscular contraction, there is a fatigue of the posture of the

muscles employed, a fatigue of the central nervous "set" which is responsible for the preservation of the favourable posture, a fatigue, it may well be, of the directive process establishing that set. Lastly, not only are the various simultaneous movements integrated together by practice so as to form a single whole, not only is there this integration of a spatial kind, but practice also brings about an integration of a temporal kind. Successive movements are integrated together, and here the influence of rhythmical performance is of the greatest aid. The value of acquiring a proper rhythm in repeated movements can hardly be exaggerated. This kind of integration likewise breaks down in fatigue.

We see, then, that if, so far as the performance of movements is concerned, industrial fatigue is to be viewed in the light of a fatigue of acquired skill, we are far removed from an explanation of industrial fatigue in terms of muscular metabolism. The fatigue must be traced largely to disorders of nervous integration, inhibition, and coördination. Its site must lie in the central nervous system.

Illustrative Examples.

Two examples, illustrative of this conclusion, may be cited from the reports of the Industrial Fatigue Research Board. In the course of their investigations into the process of "buffing" Farmer and Brooke [1] obtained wattmeter records of workers roughing (removing imperfections and scratches from) spoons and forks throughout the day. These records enabled the experimenters to detect the varying number and duration of the strokes and the varying pressure with which the workers applied each spoon and fork to the polishing wheel. As the output diminished during the day's work the worker's strokes increased in number and duration, while the pressure with which the strokes were applied became greater. In other words, with the onset of fatigue, the worker began to use extravagant energy, although the output was diminished. The skilled worker became an unskilful worker, just as happens in sport with a tired eight or a tired golfer.

The second example [2] illustrates a natural corollary from our results—namely, that it is the less efficient worker who is most susceptible to fatigue. In their investigations in boot and shoe factories, Loveday and Munro observed that those workers who achieved a high output suffered far less than their relatively inexpert comrades from the fatigue of the week's work. Whereas the latter would reach their highest

[1] Reports of the Industrial Fatigue Research Board, No. 15, pp. 45–54.

[2] Ibid., No. 10, pp. 16–28.

output at the middle of each week and fall off, often considerably, towards its end, the former would maintain their high level to the end of the week with very little or no diminution. We conclude that it is the unskilled and less productive worker who uses the most effort and who is the first to tire.

Physiology of Fatigue.

Industrial fatigue being thus pre-eminently due to fatigue of the central nervous system, we turn expectantly to our knowledge of the physiology of central nervous fatigue, but only to find an almost complete ignorance of the subject. So far as the white matter is concerned, nerve-fibres are believed to be virtually indefatigable ; the peripheral nervous impulse appears to be of a physical rather than a chemical nature ; the metabolism of the brain and spinal cord has so far proved almost inappreciable in detectable effects.

The physiological study of the fatigue of reflexes has yielded strange results, inexplicable by present conceptions of its nature. Fatigue in the central nervous system, as mechanically conceived on the basis of the study of isolated muscle, appears to be safeguarded by "the interplay of opposed agents,"[3] those of excitation and inhibition, each of which must be regarded as a relatively separate, active process and presumably as separately amenable to fatigue.

We started by treating the human organism as a mechanical engine which becomes tired when it has no longer any explosive material at its command or when it becomes clogged with the products of its combustion. But we have been led to consider central nervous fatigue as consisting not so much in the wearing out of the processes of excitation and inhibition, as in a loss of coördination, a regression from later acquired skill to lowlier earlier levels of movement, the substitution of disorder for order, the loss of higher control, organisation, and direction. Further, physiology is at present powerless to lead us. It can only recognise the facts. Biology now admits that the living organism is something more than a mere mechanism, that mere chance variations are inadequate to explain the evolution of the living world, that order and direction, culminating in purposeful individual minds, have to be taken into account. We have reached the conclusion that industrial fatigue is primarily a breakdown in that order, a loss of coördination and direction, an impairment of that psycho-physiological feature which in its highest manifestation distinguishes the mental from the merely living, in its lowest the living from the purely mechanical organisation.

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[3] Sherrington : Proc. Roy. Soc. B, 1925, xcvii., 543.

In our impotence to express this change in mechanical terms, we can only measure industrial fatigue by its direct effects. We can only safely study its effects by recourse, not to the interpolation of so-called fatigue tests, but to the actual industrial work curve. We need to measure output hour by hour throughout the working day and to study how the output rises and falls both in quality and in quantity at different hours of the day, on different days of the week, and so on. We study both curves of total output and curves of spoilt work for different kinds of work. We introduce improvements in environment—in illumination, ventilation, temperature, &c.—improvements in arrangement of the worker's material, improvements in the worker's posture, and the number, nature, and rhythm of his movements, the introduction of rest pauses in a long previously uninterrupted spell of work, better selection of the worker according to his innate abilities and interests. And we separately study the effects of these changes, one by one, upon the work curve.

We know that when the worker starts his work he has to get into his stride, to warm up to his work, to overcome distraction, to settle down to a rhythmical method of working. We know that when he resumes work after a pause he also suffers at first from having to overcome such detrimental effects. But the psychologist does not confuse these effects with loss of practice. A few minutes' absence from work does not produce any loss of skill any more than does a few minutes' pause between the repetitions of a well-learnt poem produce a loss of memory. What is lost in a short rest pause is not loss of practice but loss of what the psychologist calls incitement and settlement.[4]

During a rest pause, moreover, the effects of fatigue disappear, and in general the beneficial effects of a rest pause so far outweigh the detrimental ones that an increase in output results despite the somewhat lessened period of time actually spent at work. Thus, in the operation of packing, Farmer and Eyre, experimenting on behalf of the National Institute of Industrial Psychology,[5] obtained more than a 5 per cent. increase of output after introducing a rest pause of seven minutes in the middle of the morning's and afternoon's work, although by so doing there was a reduction by 3 per cent. in the total number of hours worked. The National Institute obtained by similar means a similar result—more than a 5 per cent. increase of output was obtained by Miles and

[4] Myers: Text-book of Experimental Psychology, Part I., pp. 180–187.

[5] Jour. of Nat. Inst. Ind. Psych., vol. i., pp. 89–92.

Bevington[6] in the process of polishing celluloid articles. Other increases, varying between 5 and 10 per cent. of output, are recorded by the Industrial Fatigue Research Board.[7]

We have yet to ascertain why rest pauses are apparently in exceptional cases of no avail. Where they have succeeded the workers have eagerly welcomed them, preferring definite organised rest pauses to the irregular periods of rest which they would otherwise have surreptitiously taken in a long officially unbroken spell of work. Rest pauses require for their successful introduction a careful preliminary study of the work curves, so that the best moment for their introduction and their duration may be determined. The work curves also require study for an accurate realisation of the effects of the rest pause. Mere increase in output is not a sufficient result to please the industrial psychologist. He demands not merely a higher *level* of curve, but an improved *form* of curve. Particularly he wants to avoid a severe fall of the work curve towards the end of the working spell.

The good effects of a rest pause, as, indeed, the good effects of reducing the total number of hours worked, may not be fully evident until several weeks or even months have elapsed. The worker needs time to become adapted to the more advantageous conditions of his work. Ideally each worker needs a different length of rest pause and a different moment for its introduction in order to produce its best effects. In practice, however, the workshop, like the school class, has to adopt procedures which are most advantageous to the majority of its members.

Mental Factors.

The work curve is likewise complicated by the presence of spurts—one of which is specially apt to occur when the end of a piece of work or the end of a spell of work, or the approach of payment is in sight. Besides the end spurt there may also be an initial spurt, when the worker comes fresh to his task with a degree of energy which soon falls off after the first few minutes. The work curve is also marked by spurts and falls at other periods, due to various mental and physical influences.

Of these mental factors the most important are of affective nature. The worker's feelings alter at his work. The feelings are of enormous importance in influencing mental and muscular work. On the one hand, they may conflict with the general attitude he

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[6] Ibid., vol. ii., pp. 269–273.
[7] Industrial Fatigue Research Board Report, No. 25.

has to maintain and the efforts which consciously or unconsciously he has to expend; or, on the other hand, they may assist in those directions. Irritation and boredom are obvious examples of the former, contentment and interest of the latter.

The influence of feelings of pleasure and displeasure and of excitement and depression on the muscular effort of which a person is capable have long been recognised by physiologists and psychologists. But the influence of conflicting feelings on the orderly character of mental and central nervous processes was only adequately realised after experience of the psycho-neuroses arising in the course of the war. The phenomena of disorder and regression there met with are but a pathological exaggeration of the same phenomena which I have stressed earlier in this address as occurring in industrial fatigue.

Just as efficient muscular work demands the maintenance of a favourable posture, so efficient mental work demands the maintenance of a favourable attitude. This attitude is, of course, maintained more easily in states of contentment and interest, less readily in states of resentment and boredom. So long as the worker is happy and interested, the favourable attitude can be preserved without effort; its preservation involves the successful inhibition of all antagonistic, incompatible attitudes. Such inhibition is apt to tire when interest fails. Discordant ideas or movements are no longer automatically suppressed. They become manifest and themselves inhibit industrial work. Conscious voluntary effort has to be invoked in order that the mental or motor task may be continued. As this wearies, boredom is felt and the need for a change of attitude becomes imperative.

We now realise how far the boredom arising from an uncongenial task may be safeguarded by a more careful selection of the worker. Too intelligent a worker for the kind of repetitive work in which he is engaged may be as unsuitable as a worker who has not sufficient intelligence for another job.[8] The work must be adapted not only to the level of general intelligence, but also to the special abilities of the worker. As a general rule, the dull worker prefers a more monotonous job. He does not want change. He safeguards himself against boredom by recourse to the phantasies of day-dreaming, to conversation, song, &c.

The effects of boredom are at first those of localised fatigue. They may be dispelled by a change of work. It has recently been found by Vernon and Bevington [9]

[8] Burnett and Wyatt: Jour. of Nat. Inst. Ind. Psych., vol. ii., pp. 18–30.

[9] Industrial Fatigue Research Board, Report No. 29, p. 48 ff.

that changes of muscular posture are extremely effective in preventing the signs of fatigue. So, too, the change of mental attitude produced by a change in the character of work may be fully as effective as the introduction of a rest pause. In one investigation Miles and Skilbeck, on behalf of the National Institute of Industrial Psychology, obtained an increase in output amounting to 14 per cent. by allotting two short periods of the morning's and afternoon's work to the collection of material by the worker, instead of distributing that collection, as had happened for the most part previously, over the working day. Similar results have since been obtained in laboratory and factory experiments conducted by Vernon and Wyatt for the Industrial Fatigue Research Board.[10]

How far boredom is an important factor at the present day in reducing industrial output cannot easily be determined. The worker's initial spirit of " buck " and interest upon entering an occupation may be so easily broken after a few weeks' engagement on routine work that he soon becomes adapted to carry out his work by recourse to those safeguards against intolerable boredom which I have already mentioned. But if actual boredom is lacking, there can be no doubt that a vast increase in quantity and quality of output could be effected if steps were taken by introducing adequate incentives to increase and to maintain the worker's interest, and hence his conscientiousness. A careful study of the most effective incentives to efficient work is therefore of the greatest importance.

Incentives to Efficient Work.

One of the National Institute's investigations[11] affords a striking demonstration of the improvement upon quality of output which may result from alleviation of the workers' irritation, annoyance, and worry. It was concerned with the breakage of china in one of the tea-shops of a large catering firm, and its success was largely due to an early recognition by Miles and Eyre, the investigators, that carelessness was not an adequate explanation of the breakages. Records were carefully taken every two hours throughout the day showing where, when, and what articles were broken. Danger points were thus revealed, and so far as possible removed. But the investigators' attention was mainly directed to overcoming the *psychological* causes of breakages, diminishing discomfort, overstrain, and sources of irritation, and facilitating the flow of work. Curves of breakage

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[10] Ibid., No. 26.
[11] Jour. of Nat. Inst. Ind. Psych., vol. i., pp. 132–140.

frequency, in other words of spoilt work, were constructed both before and after the changes recommended by the Institute had been carried out. Not only was there a diminution of over 53 per cent. in the number of breakages, not only was the curve of spoilt work at a lower level throughout the day, but it showed a far better form. The previous well-marked rise of the curve towards the end of the day's work disappeared. We may reasonably conclude, therefore, that removal of the sources of worry and irritation materially reduced the workers' fatigue. They expressed unfeigned appreciation of the improvement in working conditions introduced by the Institute.

The curve of spoilt work throughout the day has been shown by Ryan and Sargant Florence [12] to be characterised by the same features as that of output, though, of course, in inverse direction. It tends to be greatest during the initial and final hours of the morning's or afternoon's spell of work. It is also greatest among the less expert workers. The causes and hourly frequency of industrial accidents show a close resemblance to those of spoiled work. Over-pressure and irritation, especially when accompanied by fatigue and inexperience, increase the hourly frequency of accidents. Mere fatigue alone may not do so. For the worker may for a time at least work equally cautiously, but at a far lower level of output. It is when he is unduly pressed or excited that spoilt work or accidents become more frequent, and especially when such over-pressure, irritation, and worry are so great as, or have continued long enough, to be associated with fatigue.

Fatigue or Inhibition ?

At the outset we might have been disposed to define industrial fatigue as that result of previous industrial work which is manifested as a diminution in output. But, as has been shown, fatigue may temporarily result in an increased amount of work due to the tiring of higher-level inhibition and control, and it may result from many other causes than that of previous industrial work. The worker may for quite other reasons come to his work in a fatigued state. His lack of training, his use of needless movements, his whole mental and physical environment may be the true causes of his fatigued condition rather than the number of hours which he has already worked.

Further, diminution of output as the work continues may result not only from fatigue, but also from lack of incentive or boredom, resentment, and worry

[12] Ibid., vol. i., pp. 193–197.

—causes which if prolonged and resisted will ultimately cause fatigue, but the removal of which in their early stages of occurrence will at once produce a rise of output. Their adverse influence on output is initially due to temporary inhibition. How are we to distinguish industrial fatigue from inhibition? Only, I think, by observing the effects of removing their respective causes. If the reduction of output at once disappears, we may justly attribute its causes to previous inhibition. If the reduction of output is gradual, we may (with less certainty) attribute its cause to previous fatigue.

In the majority of cases under present-day conditions industrial fatigue is not to be reduced by shortening the hours of the day's work. It is to be combated rather by the avoidance of too long uninterrupted spells of work, by the introduction (after careful study of the work curve) of rest pauses, and of change of work and posture, by determination of the best movements of the worker, by systematic training of the worker in those movements, by selection of the worker so that his occupation is adapted to his innate abilities, by the abolition of causes of needless resentment, irritation, and worry, by the introduction of suitable incentives to work, by the provision of a good physical environment in regard to illumination, temperature, humidity, ventilation, food, &c.

As we have seen, industrial fatigue is too complex, and our knowledge of the physiology of the nervous system is too rudimentary, to allow of a definition of its character in physical and chemical terms. Indeed, it may be of a nature that forbids complete definition in the language of pure mechanism. At present it can only be studied and estimated by means of industrial work curves—curves of output and curves of spoilt work, indicating variations in the quantity and the quality of the worker's products. We must never forget that industrial fatigue involves not merely a diminution in the quantity of the worker's available "energy," but also a lack of harmony, a disorder of the various nervous processes which determine his performance of mental or bodily work.

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